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Filmless Radiology: The Design, Integration, Implementation, and Evaluation of a Digital Imaging Network

The Applicability of Digital Imaging to the U.S. Army Combat Medical Care System

Annual Report

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To date, most of the U.S. Army's medical imaging requirements for combat care have been satisfied by conventional x-ray techniques. While effective, units employing such techniques require extensive logistics support and provide somewhat limited capabilities in the combat zone. Digital technology may offer an opportunity to improve capabilities while reducing the logistical support for field radiology. This paper provides a top-down perspective of the Army's medical digital imaging needs with an eye towards promoting further discussions on the role, operations, and evaluation of a Digital Imaging Network System (DINS). A DINS is an automated and integrated information management system for processing, storing, retrieving, and displaying radiological images and related clinical information. This report was first published in November 1987 and has been revised to reflect the sponsor's subsequent review.

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1.0 INTRODUCTION

To date, most of the U.S. Army's medical imaging requirements for combat care have been satisfied by conventional x-ray techniques. While effective, units employing such techniques require extensive logistical support and provide somewhat limited capabilities in the combat zone. Digital technology may offer an opportunity to improve capabilities while reducing the logistics for field radiology. Furthermore, it can serve as the bridge between various levels of the medical care system, enhancing continuity of care for the injured as they move from mobile to fixed facilities in the Theater of Operations and the Continental United States (CONUS).

The advent of digital modalities in radiology, such as computed tomography, ultrasound, digital radiography, and others, brings the concept of filmless radiology closer to reality and drives the development and implementation of the Digital Imaging Network System (DINS). A DINS is an automated and integrated information management system for processing, storage, retrieval, display, and communication of radiological images obtained from medical imaging modalities and of clinical information obtained from other information systems. Figure 1-1 illustrates the basic DINS concept of acquiring image and patient data from acquisition stations and information systems, and storing the data for later display on multi-modality workstations.

This paper provides a top-down perspective of the Army's medical digital imaging needs with an eye towards promoting further discussions on the role, operations, and evaluation of a DINS. The specific objectives of this paper are threefold:

1. To describe the Army's current methods and plans for supporting medical imaging, with emphasis on combat care

2. To discuss how digital imaging technology may fit into the Army's medical imaging structure

3. To suggest ways in which the DINS can serve as a testbed to determine how well digital imaging can meet the Army's long-term imaging needs

The U.S. Army combat medical care system is described in Section 2.0, with emphasis on digital imaging capabilities and needs. The benefits of a digital imaging system and possible network configurations are discussed in Section 3.0. The testbed role of DINS and special areas for further investigation are addressed in Section 4.0. A summary and conclusions in Section 5.0 complete the main body of the paper. Appendix A contains a glossary of acronyms, and references appear in Appendix B. The reader's

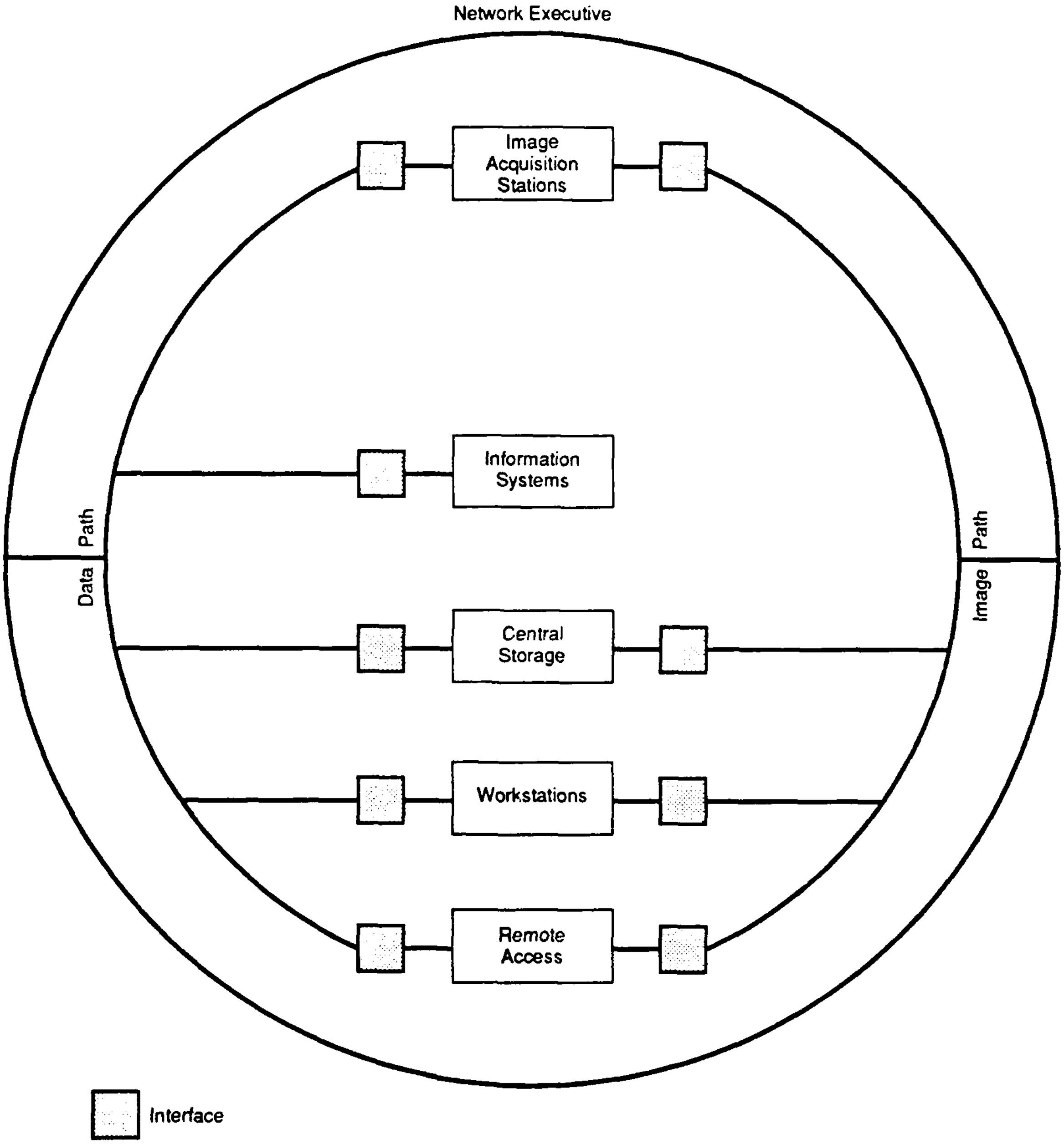


FIGURE 1-1
THE DINS CONCEPT

attention is also directed to a companion document titled "The Digital Imaging Network System and Its Potential Impact on Quality of Care in the U.S. Army Peacetime Medical Care System," (The MITRE Corporation, November 1987) that addresses digital imaging in fixed medical facilities.

This paper is based on the authors' attendance at meetings convened by the U.S. Army Medical Research and Development Command (USAMRDC), e.g., the meeting on Diagnostic Imaging for Combat Casualty Care (17-18 April 1986, Ft. Detrick, Maryland); a review of published literature and documents prepared by the USAMRDC; discussions with military staff and civilians knowledgeable in military medicine and/or radiology; and MITRE's experience with medical systems and related technologies.

Earlier MITRE activities that led to our commitment to the DINS project focused on remote consultation as a means to meet the radiological information needs of small military and civilian hospitals in locales that could not attract or support full-time staff radiologists. Remote consultation relies on the transmission of digitized x-ray images from one geographic location to another using telephone lines or other electronic means for purposes of providing specialty care to distant locations. With funding from the U.S. Army, and in cooperation with the Public Health Service, MITRE conducted two field trials in 1982 and 1984, which demonstrated that one can expect video readers to obtain essentially the same findings and impressions on cases in primary care radiology as film readers.[1,2] These investigations led to convening a group of experts who consulted with MITRE in defining the functional requirements and technical specifications for the digital imaging network system discussed in this paper and currently being evaluated for implementation in the 1990s.

References appear in Appendix B.

2.0 U.S. ARMY COMBAT MEDICAL CARE SYSTEM

The Readiness Mission is central to all components of the military medical departments, including the medical corps in the combat zone who has the specific treatment and triage responsibilities of providing care to the injured and returning those able to continue fighting in the battle area. Where necessary, the more seriously wounded are evacuated to rear facilities for specialized care.

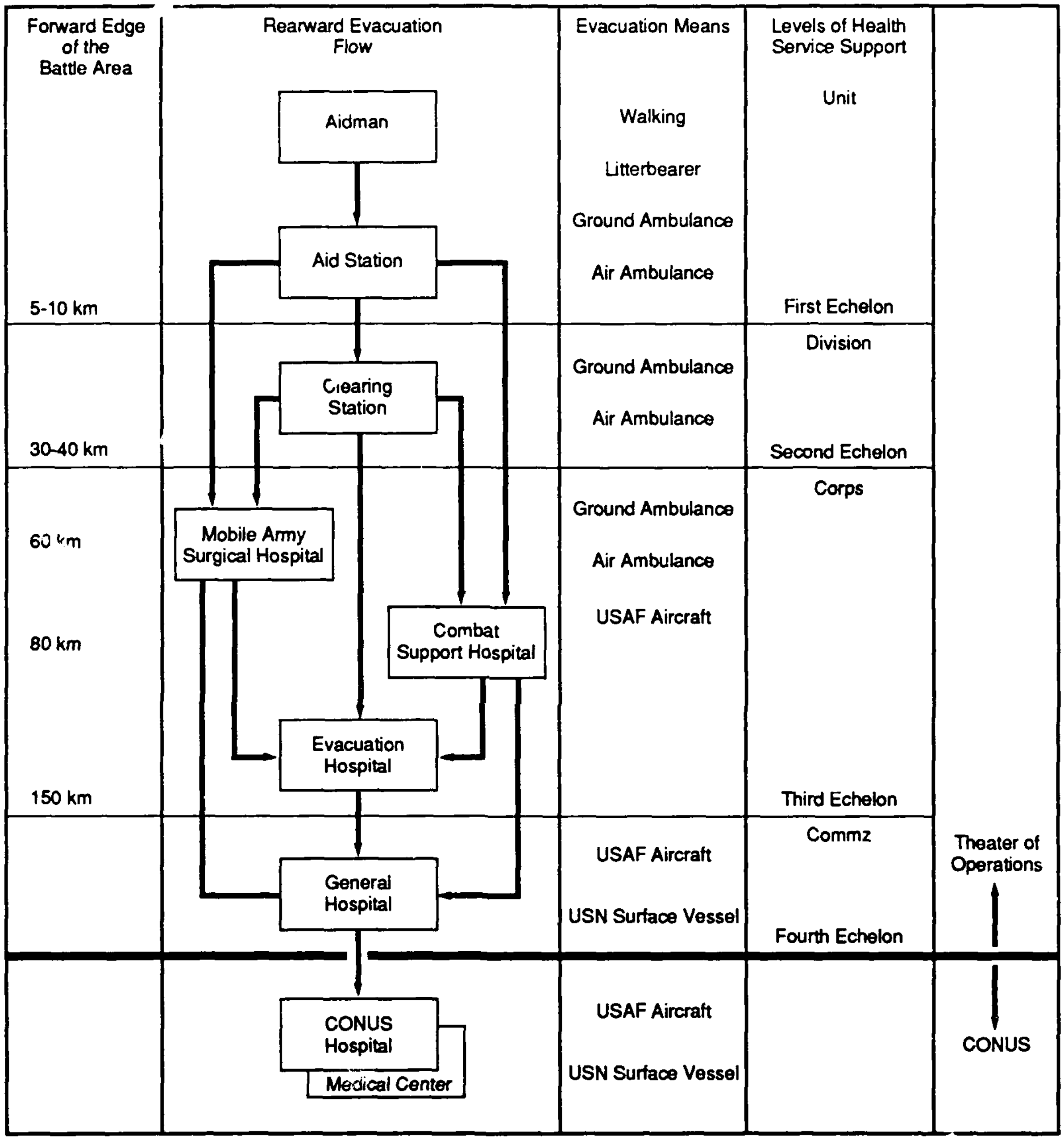
The medical corps' readiness for major conflicts is debated in the military medical literature.[3,4,5] Of special significance to the subject of this paper, however, are new grams and technologies that may enhance the survivability of the combat soldier and the quality of care of the wounded in future conflicts. These are also highlighted in the literature[6,7] and have been the subject of discussion at key meetings convened by the Army to examine end user requirements. Digital imaging falls within the latter category of new technologies with potential for improving medical corps readiness and care delivered to the wounded.

In this section we first describe the organization of the medical care in the combat area and the plans for Deployable Medical Systems. Field imaging capabilities in the short and long term are then described, and the hardware compatibility issue is discussed.

2.1 Organization

Health service support in the combat area is provided at the unit, division, corps, and communication zone levels, as depicted in Figure 2-1. Care at the first three levels is delivered from mobile facilities located up to 10, 40, and 150 kilometers from the forward edge of the battle area, respectively. Fixed Army hospitals/clinics located overseas as well as general hospitals in occupied zones or in nearby friendly nations serve as health care delivery sites in the communications zone. Examples of the latter are hospitals in France or England for the North Atlantic Treaty Organization (NATO); Japan, Guam, Philippines, for Korea; and Israel or Germany for mid-East conflicts. If additional treatment or rehabilitation services are required, the soldier is transported stateside for entry into a CONUS hospital or medical center, with a final disposition of (1) return to active duty, (2) discharge to civilian status, or (3) entry into the Veterans Administration (VA) hospital system.

Specific health care delivery goals vary at the different echelons. Maintainability of an adequate combat force is a primary objective at the Division level where first aid and emergency medical and dental care are provided, simple surgical procedures are carried out, and stress management and preventive health activities are conducted. Minor surgery is performed under local anesthesia at Clearing Stations in the Division level whereas



Source: Theater of Operations portion obtained from the U.S. Army Medical Research and Development Command, Ft. Detrick MD.

FIGURE 2-1
U.S. ARMY MEDICAL DEPARTMENT TREATMENT AND EVACUATION SYSTEM

more serious wounds are treated under general anesthesia at the Corps level. Only when a soldier is moved to the fixed hospital in the fourth echelon is he considered no longer able to return to combat duty because of his wounds.[8]

Hospitals for the U.S. Armed Forces are designed modularly according to the Deployable Medical System (DEPMEDS) concept. Facility characteristics vary by type of hospital, but all meet the systems criteria of providing adequate but austere care, being affordable, maintainable, relocatable, configured modularly, and transportable by strategic air. Under the auspices of the Department of Defense (DoD) Medical Standardization Board, the DEPMEDS hospitals will standardize the use of the latest medical technology and equipment, expendable supplies, and major non-medical support equipment (e.g., power units, tactical shelters, heating and air conditioning). In the combat zone, modular DEPMEDS facilities with standardized equipment will improve medical unit mobility and flexibility to support changing mission requirements dictated by the threat and patient distribution densities.

There are seven types of U.S. Army hospitals, ranging from forward deployed Mobile Army Surgical Hospital (MASH) units in the combat zone to general hospitals in the Communications Zone (COMMZ). Each is composed of different configurations of standard DEPMEDS modules, such as operating rooms, laboratories, x-ray units, and wards, and can be deployed under all climatic conditions. For example, at the Corps level, the MASH unit has 4 surgical suites, 60 beds, x-ray, laboratory and pharmacy services. Planned to be deployed closer to the Division and in service on a continuous 24-hour basis, the MASH meets the requirement for a more flexible hospital than the larger and less mobile Evacuation (EVAC) Hospital and Combat Support Hospital (CSH).

Fielding of the 160 Army DEPMEDS hospitals will begin in the fourth quarter of fiscal year (FY) 87 and continue through FY 93. Units will receive their DEPMEDS equipment in one package under the Total Package/Unit Materiel Fielding concept, the largest such effort ever undertaken by the Army Medical Department. An integral part of the DEPMEDS package will be equipment for diagnostic imaging, as discussed elsewhere in this paper. It is anticipated that fielding of the DEPMEDS-equipped Army hospitals will eliminate serious shortages of field medical equipment and achieve major advances in equipping the total Army.

2.2 Field Imaging Capabilities and Requirements

> "A wounded man...can (not) be deposited at the boundary of an echelon and responsibilities dismissed. Only by coordination of policy and method between echelons can military surgery attain its full stature."[9]

If this statement, made over 40 years ago, holds true today for military surgery, then it has implications for field radiology. As shown in Figure 2-2, digital images and patients are hypothesized to move between the several echelons of care. Images taken earlier in the forward area (if transported with the patient) can provide valuable insights into reasons for initial treatment and reveal subsequent changes in the patient's condition. This knowledge has the potential to enhance continuity of care and effectiveness of the health care services provided. But if an armed conflict were to break out today, only conventional x-ray equipment, described seven years ago as inadquate for field use, would be available for diagnostic imaging. However, a high capacity (HICAP) x-ray system is currently under development by Picker International that will replace the existing conventional x-ray equipment in the facilities at the Corps level by the late 1980s. Already designed, developed, and initially tested, the equipment is undergoing further operational testing at Fort Sam Houston, Texas. Action has recently been taken to procure a low capacity (LOCAP) x-ray system for deployment as far forward as the Division level. A proof-of-concept study has been funded to investigate the feasibility of a field computed tomography (CT) scanner; and the Army is cautiously optimistic about the Navy's progress in developing a lightweight ultrasound device with possible applicability to the Army's combat medical care system.

Future developments expected in digital imaging include: memory screens, Electrophoretic Image Display (EPID) reusable image panels, dry silver printers, low-power capacitor discharge devices, image storage cassettes, and optical memory cards, among others.[10]

The urgent need to develop filmless imaging systems for field use was highlighted in the 1986 Operational and Organizational (O&O) Plan for Field Diagnostic Imaging Systems.[11] The deployment of a spectrum of imaging equipment in DEPMEDS facilities, from very lightweight/portable systems through mobile CT systems, could improve patient care and reduce logistical support while improving diagnostic imaging capabilities. Table 2-1 contains key items related to the delivery of care in the Theater of Operations, including a list of diagnostic imaging systems that have been cited in the literature, or at meetings, as appropriate to the various organizational levels of the combat care medical system.

The urgency expressed by the Army vis-a-vis the development/procurement of appropriate filmless diagnostic imaging equipment for its medical care system is well-founded, considering how quickly the technology is changing and how slowly equipment can be developed, tested, and deployed for military use.

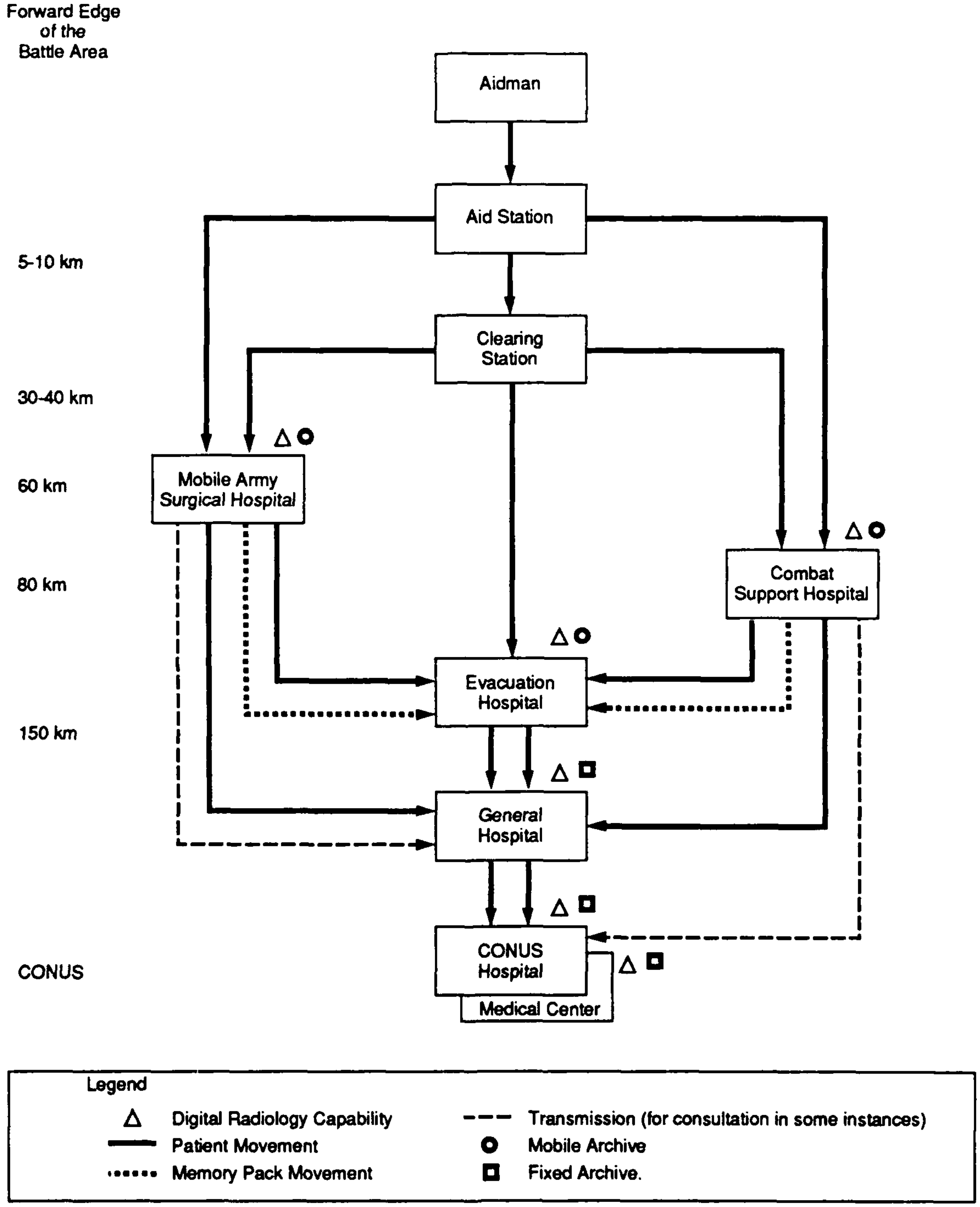


FIGURE 2-2
DINS TECHNOLOGY HYPOTHESIZED IN THE ARMY MEDICAL IMAGING SYSTEM

TABLE 2-1
COMBAT CASUALTY CARE SYSTEM CHARACTERISTICS AND IMAGING NEEDS

Organization Level		Facility	Number of		Level of Care	Disposition	Imaging
			BEDS	ORs			
Unit	Mobile	• Battalion Aid Station (BAS)	0	0	• Resuscitation • Treatment of Shock • Control of Hemorrhage • Splinting	Return to unit or move to next level	• None
Division	Mobile	• Clearing Stations (CS) - Forward Medical Companies (3) - Rear Medical Support Company (1)	160	0	• Resucitaiton • Simple Surgical Procedures with Local Anesthesia • Emergency Medical Care • Dental Health Care • Mental Health Care • Preventive Health CAre • Optometry	Return to unit within 96 hours or move to next level	• LOCAP X-ray • Hand-held X-ray
Corps	Mobile	• Surgical Hospital (MASH) (1) • Combat Support Hospital (CSH) (1) • Evacuation (EVAC) Hospitals (2)	1,060	20	• All basic services normally found in civillian hospital, including surgical procedures with general anesthesia	Return to unit within 96 hours or move to next level	• HICAP X-ray (Fluoro Optional) • Mobile CT • Hand-held X-ray (bedside) • Portable Ultrasound
COMMZ	Fixed	• General Hospitals	Variable			Return to active duty/discharge from service/or move to other hospital or medical center	• HICAP X-ray • Fluoroscopy • Ultrasound • Nuclear Medicine • CT • MRI

( ) = Number of facilities per organization level.

2.3 Field Imaging Compatibility Issues

Compatibility of digital imaging components becomes a critical element from a system's viewpoint. Ideally, any digital image generated anywhere within the military's medical system should be capable of being viewed on any digital image display device or stored on any digital image storage unit within the military medical system. For example, images taken far forward should be readable at all echelons of military medical facilities and beyond. Images must be movable across echelons despite variations in format, acquisition method, or storage medium. Problems arise because different modalities generate different image formats, and the same functional hardware components may be produced by more than one manufacturer. Special emphasis is now being placed in the imaging community upon developing, evaluating, and enforcing standards; specifically, the American College of Radiology/National Electrical Manufacturers Association (ACR/NEMA) standard is the currently proposed standard to be used for interconnection of medical imaging devices.

In pursuing compatibility between services and across echelons of care, a number of technical issues must be resolved. Some key areas requiring special investigation include the following:

- Image Spatial Resolution--If a standard resolution is not agreed upon for all devices, should all devices be designed to support processing (display or storage) of images of arbitrary resolution? Will conversion for display (e.g., displaying a 1024 x 1024 image on a 512 x 512 unit) cause unacceptable degradation?

- Image Contrast Resolution--What number of bits per picture element (pixel) or number of gray levels per pixel, is optimal?

- Image Processing Techniques--If a particular technique/device is required to adequately view an image (e.g., zooming or edge detection), should all display units support the capability? If the required capability is unavailable at a particular station, should the system warn the user accordingly?

- Image Headers--Must all images contain descriptors defining their characteristics (resolution, etc.) and describing how they were viewed when the original diagnosis was made (display parameters)?

Digital imaging, whose benefits are described in the next section, provides an opportunity for improving radiological services across the organizational levels of the military care system. The development of a DINS testbed, discussed later in greater detail, is a means to reaching this end. It can play a major role in investigating the topics outlined above, as well as others, and in determining device compatibility. It can lead to the design, development, and implementation in the 1990s of a scaled-down, field-deployable DINS in the DEPMEDS facilities.

3.0 BENEFITS OF A DIGITAL IMAGING SYSTEM

The use of digital systems for medical imaging purposes in battlefield situations can yield an improved efficiency in the acquisition, archive, display, and transmission of images. This section discusses how these benefits are realized and how the equipment could be configured at the various echelons. Table 3-1 summarizes the benefits discussed in this section.

3.1 Image Acquisition

Developing x-ray films is a tedious process requiring chemicals and water, temperature control, and a clean environment. The films themselves are sensitive to the storage environment and ideally must be kept in cool, dark, and dry storage.

These conditions can be adequately met in the laboratory environment of a hospital, but processing x-ray film in the forward areas of battle is a formidable task. Furthermore, transportation of the chemicals used in film processing to the forward areas is expensive and hard to manage, and controlling the environment for storage of x-ray films is difficult due to fluctuating temperature and humidity ranges.

Obtaining an electronic image directly and displaying it on ruggedized hardware, rather than by generating an x-ray film and digitizing it, can make the process of providing x-ray images in the field much less tedious, easier, and less costly and can result in images of uniform quality. Several vendors purport to have the basic medium to replace the photographic film.

3.2 Image Archive

The ability to produce images in a digital format, rather than on photographic films, yields improvement in the efficiency and reliability with which medical images can be transported and archived. Storing digital representations of the images on magnetic or optical disks can reduce the amount of space required for archiving films; increase the speed with which images can be indexed, grouped, and retrieved; and reduce the likelihood of lost images. A communications network can be utilized to retrieve digital images, group images together based on a user-defined indexing scheme, and retrieve images on a monitor at a location remote from the archive area. This is a more efficient method of collecting and distributing images than a manual search of a film library and subsequent transport of the films, if found, by mail or by hand.

TABLE 3-1
BENEFITS OF A DIGITAL IMAGING SYSTEM

Image Acquisition	• Obviates use, storage, and transportation of chemicals, water, and film • Allows better quality control
Image Archive	• Allows fast access to all images • Eliminates problems due to lost films • Prevents degradation of archived images
Image Display	• Supports image processing techniques to enhance artifacts • Allows use of artificial intelligence techniques to aid in diagnosis
Communications Networks	• Supports fast, reliable transport of images between acquisition stations, viewing stations, and the archive • Allows interconnection of facilities

Backup is also facilitated by digital storage. Film copies will inherently have some distortion and degradation due to the physics of the process involved, whereas there is no additional error added to a digital image by making copies. As long as the digital data (the 1's and 0's) remain intact, the image will not incur errors. Digital representations of images have a robust character that their analog counterparts do not have. Any noise added to a digital signal will not necessarily degrade the signal; degradation occurs when the 1's and 0's change state. Analog signals, on the other hand, are changed by any noise added to them. The only errors in a digital representation of an image (or signal) are the distortions that occur when the image is originally digitized. For the purposes of assuring a lasting copy of the image, a digital-based archive system meets this need.

Digital images are also easier to store in an adverse environment than images stored on a film. Films are susceptible to the heat, humidity, mud, water and other environmental factors that are part of the battlefield scenario. It is difficult to "ruggedize" photographic films. On the other hand, silicone-based memory and optical disk cartridges can be fabricated to tolerate the battlefield environment and still offer a means of storing and transporting medical images with the patient from the forward areas back to the supporting medical treatment facilities. While most large-scale digital archive units will be located at large hospital facilities, with field images being transported back for entry into the archive, portable archive units will be used in the field.

3.3 Image Display

The ability to display digital images from memory allows flexibility in the manner in which images can be viewed on the various sizes of display screens that are available. Images can be easily grouped together (e.g., images from different modalities or x-ray images of a particular area from different angles), and the digital data can be manipulated so as to extract information that might be otherwise overlooked.

This ability to manipulate an image is one of the fundamental benefits of the digitally stored image that a film or associated photographic process lacks. The digital image can be quickly reduced or enlarged in display scale (zoomed); the quantization parameters for the image can be modified to select a particular range of gray levels (gray scale stretching); and signal processing can be used to emphasize edges, curves, or other features of interest to the health care provider. It is also possible to correct for false artifacts in the image, which might otherwise impair a proper diagnosis. This capability of processing images, so as to enhance them and correct for image degradation due to battlefield conditions, should be a major benefit to the overall combat casualty care system.

Medical images in a digital format also facilitate the application of computers in the recognition and diagnosis of certain conditions appearing in a medical image. By means of shape analysis and shape recognition, a computer-based system could assist by suggesting possible diagnoses, or the display console could function as an expert system by recommending certain types of digital enhancements to better view certain types of images. These capabilities could prove useful where specialty services are not always available.

3.4 Image Transmission

Some means of communication, manual or electronic, will be required to move images between nodes (i.e., across echelons) and within nodes (i.e., within a facility).

3.4.1 Inter-node Communication

Digital data can be transmitted over networks much more quickly than films can be sent by traditional means. High-speed imaging networks will most likely be located only at large hospital facilities; however, images could move between echelons by handcarry transportation or, in rare cases, by transmission over communication channels. If an image is generated in the forward area, the data can be physically stored on a magnetic or optical medium and transported with the patient. In peacetime, hardwire, fiber optics, or satellite links may conceivably be utilized for the transmission of images.

3.4.2 Intra-node Communication

Communications within a facility can be handled by commercially available local area networks (LANs). These LANs can support all of the communications requirements associated with the digital imaging equipment, including voice, video (analog), digital images, and textual data. Generally, these LANs increase in complexity as the size of the facility increases. At all sites (except CONUS), however, the LANs must be portable to permit installation and de-installation with a minimum of calibration and setup time. In all probability, these LANs would not rely on civilian telephone companies but rather would require dedicated equipment.

3.5 Configurations for Digital Imaging Network

Digital imaging equipment will be incorporated into the echelons of care to varying degrees. Table 3-2 summarizes how this equipment could be distributed. Generally, as one moves away from the forward area, the systems become larger and more complex, support more display stations, support larger local archives, and are less transportable. Figures 3-1 through 3-4 present possible configurations for equipment that could be installed within the third and fourth echelons. It should be noted that each of the configurations supports some form of a local archive unit. The lack of availability of sufficient communication bandwidth during wartime prohibits implementation of a central archive serving all echelons of care. As communication channels will not be available for transmission of medical images, movement of data between archives will be handled manually.

3.6 General Technical Specifications

Although functional requirements and technical specifications for a DINS appropriate for general and CONUS hospitals were defined and documented in 1985-1986 by a group of radiologists, engineers and scientists from several universities, government agencies, military services, and MITRE,[12,13] detailed technical specifications must be prepared for all equipment to be installed at each echelon in the combat casualty care system. Some general specifications apply regardless of echelon. These are:

- The equipment must be capable of being used for long periods with little or no maintenance
- The equipment must be transportable and operable in harsh environments
- Setup and calibration time must be minimal
- The equipment must support redundant hardware and manual backup to ensure availability
- Image and demographic data acquired, transmitted, and stored by the equipment may have to be encrypted
- Interservice and interechelon compatibility are required, including:
  - Image file format (affects resolution and display)
  - Physical transport media (i.e., how images are moved between devices)

TABLE 3-2
DIGITAL IMAGING IN THE COMBAT MEDICAL CARE SYSTEM

Echelon	Acquisition	Communication	Archival Storage	Display
Clearing Station	• LOCAP X-ray Hand-held X-ray unit	• Hand carry	None	• Small, ruggedized display
MASH CSH EVAC Hospital	• Mobile CT EPID Portable Ultrasound Hand-held X-ray (bedside-use) HICAP X-ray unit	Inter-Site • Hand carry memory packs • Possible use of communications channels for consultations Intra-Site • Small LAN for 2 nodes	• Possibly a portable archive; else, hand carry images to next echelon	• Small, single-screen units • Possibly, display attached to imager
General Hospital (Non-CONUS)	All Modalities	Inter-Site • Hand carry memory packs to CONUS Intra-Site • Large LAN, multi-channel, multi-media, 4 to 8 nodes, mobile DINs	• Larger, fixed archive (computer center type operation) Need not be ruggedized	• Larger, multi-screen displays
CONUS	All Modalities	Inter-Site • High speed LAN • Satellite and landline communications Intra-Site • Large LAN, full scale DINs, 8 to 20 nodes	• Mass storage, optical jukeboxes	• Sophisticated, multi-screen workstations replacing viewboxes

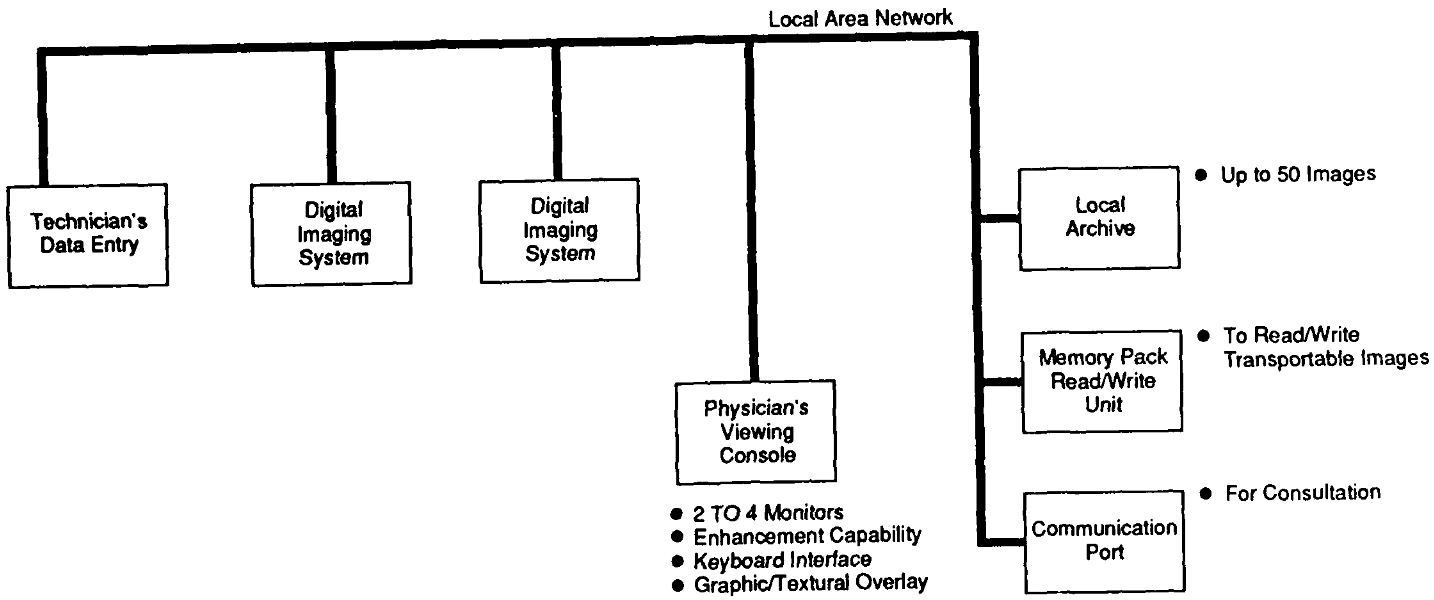


FIGURE 3-1
POSSIBLE CONFIGURATION OF A DIGITAL IMAGING NETWORK IN THE MASH UNIT

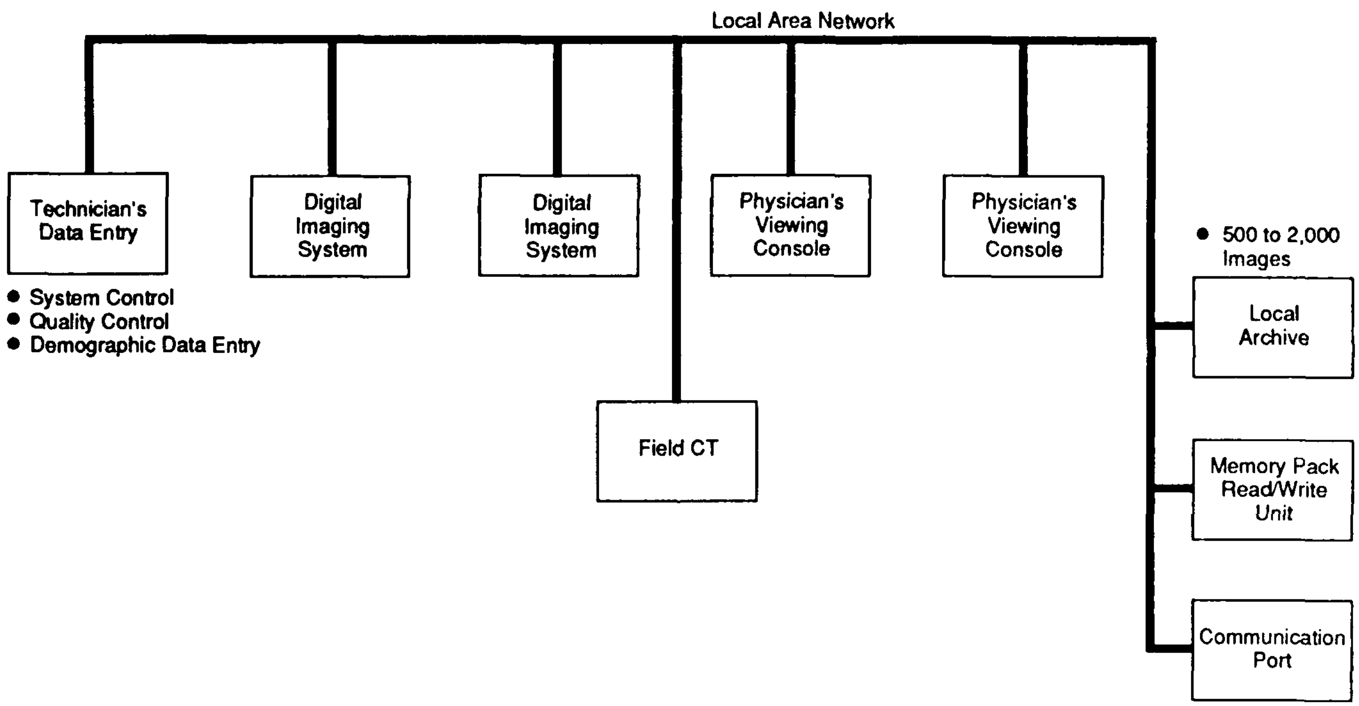


FIGURE 3-2
POSSIBLE CONFIGURATION OF A DIGITAL IMAGING NETWORK IN A COMBAT SUPPORT HOSPITAL

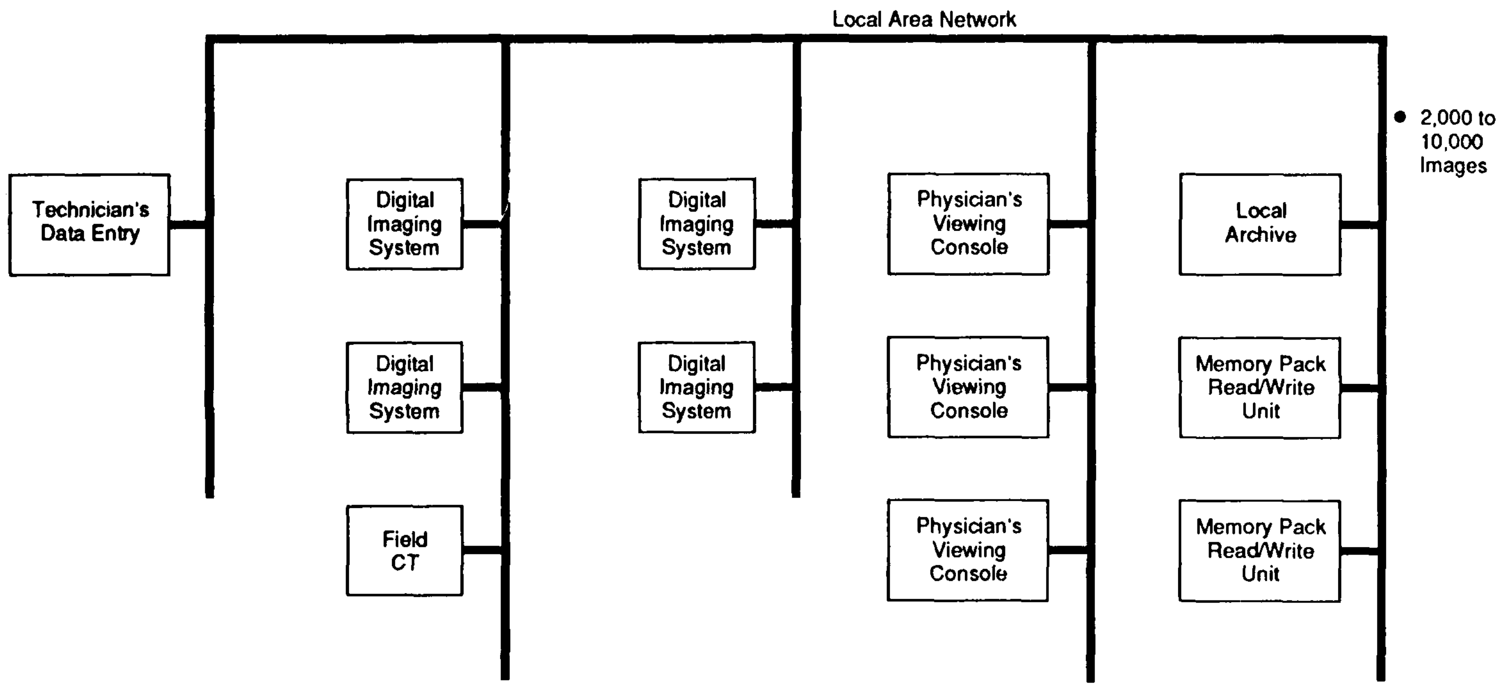
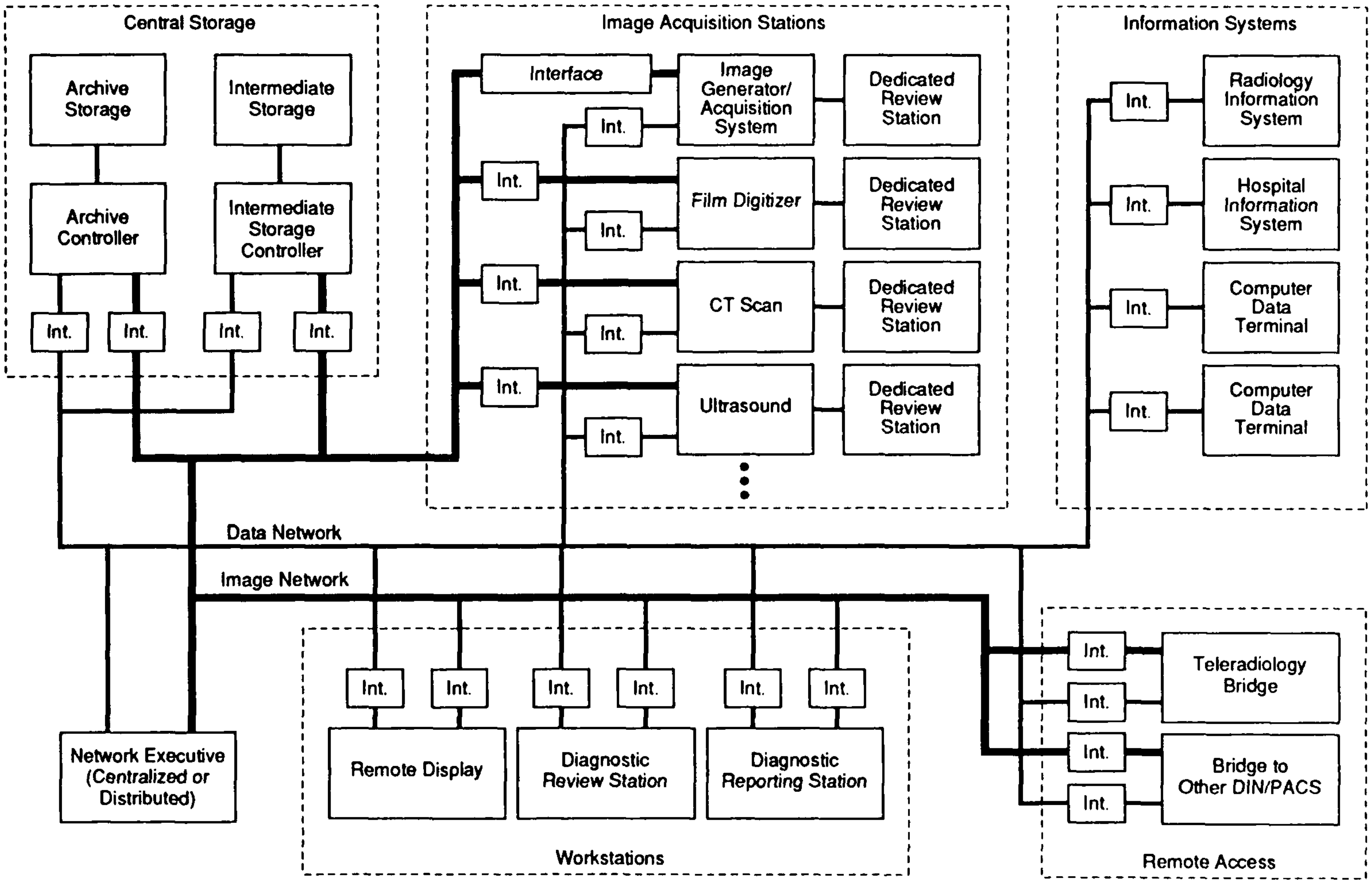


FIGURE 3-3
POSSIBLE CONFIGURATION OF A DIGITAL IMAGING NETWORK IN THE EVACUATION HOSPITAL



Key: Int. = Interface function required at each node on the network

Source: "Technical Specifications for a Hospital-Based Digital Imaging Network," The MITRE Corporation, MTR-85W242, January 1986, p. 2-11

FIGURE 3-4
POSSIBLE CONFIGURATION OF A DIGITAL IMAGING NETWORK IN THE GENERAL AND CONUS HOSPITALS

- Data encryption methods

- Demographic data requirements

3.7 Reliability and Degraded Mode Operation

The equipment under discussion will be subjected to harsh environments and will be required to operate in critical situations. It is essential that any specifications for such equipment not only emphasize initial reliability requirements but also establish procedures whereby the equipment still provides some level of service after failure. Such specifications would include the following:

- Redundant hardware and built-in spare parts

- Self-diagnosing hardware

- Capability of operating with reduced functionality

- Modular systems to facilitate "on-the-spot" reconfiguration

4.0 DINS AS A TESTBED SYSTEM

Prior to implementation of field operational units, a number of areas must be investigated in order to develop meaningful specifications. Some of the important areas can be investigated on a DINS testbed capable of demonstrating various types of data acquisition, storage, image transport, and display features. Special studies to be conducted on the DINS testbed will lead to a more fully integrated, compatible digital imaging network to support and improve combat casualty care. There are a minimum of four major areas of investigation to be pursued: human factors, fieldable/transportable imaging media, image processing techniques, and operational studies. These are discussed below in terms of some specific topics to consider in greater detail at a later date.

4.1 Human Factors

The investigations in the human factors area are concerned with simplification of the process of providing medical images for combat casualty care. These studies concern (1) the man/machine interface in terms of the health care provider's and radiologist's interaction with digital imaging and display equipment and (2) simplification of the training procedures associated with the production and storage of medical images.

One of the goals in integrating digital imaging systems into the existing combat casualty care system is to facilitate interaction and consultation between the health care provider and the radiologist. The ease with which the user can interact with the equipment will be critical to the user's acceptance of the system. Success at this is dependent upon how well the man/machine interface is designed. There are two main areas of consideration with regard to the interface between the system and the user: (1) the physical environment and configuration of the equipment and (2) the software/operating system.

One of the primary concerns regarding the physical environment is the ambient light that reflects off monitor screens. This is especially important when considering the battlefield environment where there is less control over lighting than in the hospital setting. The possible effects of ambient lighting must be considered in selecting monitor type, e.g., tilt versus nontilt, nonglare screen, etc.

The arrangement of the equipment at the different types of workstations, as well as the type of equipment chosen, may also affect user interaction with the system. The viewing screens must be arranged such that all of the displays are easily visible to the user, requiring a minimum of head movement.

In addition to the display, devices used to control the equipment (e.g., keyboard, joystick, mouse, voice control, etc.) must be evaluated. The requirement to move existing digital imaging capabilities from the hospital environment to an environmentally harsh field environment may require investigation of new methods of human interactions and may result in changing established professional work habits.

Additional issues in the area of human factors research requiring investigation include the following:

- Simplified operation
- User training
- Artificial intelligence approaches to assisting the user
- Streamlined procedures to support use in demanding situations

4.2 Fieldable/Transportable Imaging Media

The ability to represent an image in a digital format allows for storing images in a ruggedized medium, thus promoting easier transportation from the forward to the rear areas. Not only is processing x-ray films in the forward areas complicated by the need for chemicals, but also it is difficult to ensure that an x-ray film generated at one echelon will be transported with the patient to facilities in other echelons. For these reasons, there need to be further investigations into which media are most appropriate for the storage and transportation of medical images in the battlefield environment. Given current technology, it is anticipated that a film replacement will be used whereby procedures are performed by exposing the film replacement on a conventional x-ray machine with the resultant image being transferred from the film replacement to a digital storage unit. Two possible technologies for such use are the EPID panel and the optical memory card. Once in digital format, images can be transmitted between facilities by handcarrying memory packs, optical disks or cards, or, in rare circumstances, transmission over communications networks may be used. Existing digital modalities (e.g., CT) would not require an intermediate stage similar to the EPID panel.

4.3 Image Processing Techniques

One of the primary considerations in determining the effectiveness of digital imaging is the user's perception of the digital image quality as compared to that of the original image on photographic film (such as the x-ray). Image processing, i.e., the mathematical manipulation of the gray level values of the pixels (or picture elements) which comprise the image, can play a role in this aspect. There are at least three main areas of image processing to be considered in special studies: image quantization, image compression, and image enhancement.

The investigations to be performed in the area of image quantization will deal with the number of bits per pixel needed to properly represent the original image. Given that the monitors available for viewing digital images generally have only 256 discernible gray levels, represented by eight bits of data, it is important that those eight bits are properly distributed over the dynamic range of the original image. This investigation will involve the modeling (or, finding an expected histogram) of the various types of images (CT, digital subtraction angiography (DSA), and especially x-ray images) and then designing a quantizer appropriately.

Image compression is essentially a data reduction technique. Characteristically, there is a high degree of correlation between the gray levels of adjacent pixels in an image; it is this correlation which image compression exploits to arrive at a reduced data form for the original image. Compressed images increase storage capability and reduce bandwidth requirements for the transmission of images. Many types of image compression algorithms are available.(14) Studies done in this area will focus on finding the best algorithm in terms of preserving the information content of the original image.

Image enhancement involves processing an image to extract features and to enhance, or detail, different types of information. It can prove beneficial for the system to accentuate certain features of interest to aid the health care provider in his/her analysis. For example, edge enhancement techniques can be used to assist in detecting small bone fractures in an x-ray which might be hard to detect otherwise. Image enhancement can also be used to correct for sampling inaccuracies in magnetic resonance images (MRI) and to correct for image degradation in ultrasonic imaging due to the noise involved in the process.

4.4 Operational Studies

Investigations into the areas of image quantization, image compression, and image enhancement can theoretically improve the efficiency of the system and the quality of the image information. To put these types of investigations into a practical perspective, however, it is necessary to have feedback from operational studies. Reliability, compatibility of components, and system response times are other topics that can be investigated in an operational setting.

These topics, in addition to many of those already discussed, e.g., the man/machine interface, would be invaluable in providing guidance with regard to the feasibility, utility, and design of the various components in a digital imaging network stretching from the forward battle area to the CONUS facilities.

5.0 SUMMARY AND CONCLUSIONS

In this paper the authors have described medical imaging requirements from a systems perspective and discussed how a DINS testbed can be employed to further the development of requirements and specifications to meet the Army's medical imaging needs in the battlefield. It was noted that only conventional x-ray equipment, inadequate for field use, would be available for radiographic imaging if an armed conflict occurred today. The urgent need to develop filmless imaging systems has been recognized as a means to improve health care delivery while reducing the logistical support for field radiology.

Broad imaging requirements were examined in Section 2.0 in relation to the four echelons of health service support in the U.S. Army Medical Department Treatment and Evacuation System. Plans for modular, deployable medical facilities were described, and the movement towards standardization of equipment and supplies was highlighted.

Some benefits of digital technology were addressed in Section 3.0. Digital technology is depicted as improving the efficiency and reliability with which medical images can be acquired, transported, archived, and displayed. The types of digital imaging equipment that might be appropriate at the various echelons of care in the combat care system were identified, and possible configurations for a digital imaging network were illustrated for the medical treatment facilities located in the Corps and Communication levels and in CONUS.

Issues were then raised in Section 4.0 related to the following:

- Human factors
  - Display design
  - Console design
  - User interaction
- Movement of digital images between echelons of care
- Image processing techniques for improving the quality of the digital image

The conduct of studies on a DINS testbed is suggested as appropriate at this time to resolve these and other issues addressed in this document and to begin preparing specifications of digital imaging systems for future field use.

To conclude, digital imaging technology is capable of solving existing problems associated with storage and transport of film and chemicals, image quality control, and maintenance of patient records. Additionally, it offers improvements in the area of image display, processing, and enhancement. Much of the technology required to implement these imaging systems currently exists or is under development. DINS testbed studies are called for to ensure that these digital systems are developed in a timely and cost-efficient manner to satisfy military imaging requirements.

APPENDIX A

GLOSSARY OF ACRONYMS

ACR/NEMA	American College of Radiology/National Electrical Manufacturers Association
COMMZ	Communication Zone
CONUS	Continental United States
CSH	Combat Support Hospital
CT	Computed Tomography
DEPMEDS	Deployable Medical System
DINS	Digital Imaging Network System
DoD	Department of Defense
DSA	Digital Subtraction Angiography
EPID	Electrophoretic Image Display
EVAC	Evacuation Hospital
HICAP	High Capacity X-ray System
km	Kilometer
LAN	Local Area Network
LOCAP	Low Capacity X-ray System
MASH	Mobile Army Surgical Hospital
MRI	Magnetic Resonance Imaging
NATO	North Atlantic Treaty Organization
O&O	Operational and Organizational
OR	Operating Room
USAF	U.S. Air Force
USAMRDC	U.S. Army Medical Research and Development Command
USN	U.S. Navy
VA	Veterans Administration

APPENDIX B

REFERENCES

1. Harrington, Cerva, Greene and Kerlin, "The Teleradiology Field Trial January-June 1982," The MITRE Corporation, MTR-82W216, November 1982.

2. Harrington, Miller and Kerlin, "The 1984-85 Teleradiology Field Trial Executive Summary," The MITRE Corporation, MTR-85W267, December 1985.

3. Hepps, Mercantonio, Hohmar, Bradley, Gazzariga and Simmons, "A Casualty Care Course for Increasing the Operational Readiness of Reserve Component Health Care Professionals," Military Medicine, 150, 2:97, 1985.

4. Bzik and Bellamy, "A Note on Combat Casualty Statistics," Miliary Medicine, 149, 4:229, 1984.

5. Wiener, "Medical Corps Readiness for Major Conflict," Military Medicine, 151, 6:321, 1986.

6. Livingston, "Orthopedic Management of Wartime Trauma Patients," Military Medicine, 150, 2:72, 1985.

7. Cammisa, "Modern Combat Medicine," Military Life, 28 May 1986, pp. 84-85.

8. Ibid.

9. Churchill, "The Surgical Management of the Wounded in the Mediterranean Theatre at the Time of the Fall of Rome," Ann. Surg. 120:268-283, 1944.

10. Sieband, "Digital and Conventional X-ray Systems," paper presented at the Meeting on Diagnostic Imaging for Combat Casualty Care, held at Ft. Detrick, Maryland on 17-18 April 1986.

11. "1986 Operational and Organizational (O&O) Plan for Imaging System Field Diagnostic," obtained from the Department of the Army, U.S. Army Materiel Development Authority, Ft. Detrick, Maryland.

12. "The DIN Report: Functional Requirements for a Hospital-Based Digital Imaging Network and Picture Archiving and Communication Prototype System," The MITRE Corporation, April 1985.

REFERENCES (Concluded)

13. "Technical Specifications for a Hospital-Based Digital Imaging Network," The MITRE Corporation, MTR-85W242, January 1986.

14. Jain, "Image Data Compression: A Review," Proceedings of the IEEE, Vol. 69, No. 3, pp. 349-389, March 1981.

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